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(71) Applicant
Philips Electronic and Associated Industries Limited

(Incorporated in United Kingdom)

Arundel Great Court, 8 Arundel Street,
London, WC2R 3DT

(72) Inventor
John Alfred Clarke

(74) Agent and/or Address for Service
R. J. Boxall
Philips Electronics,
Patents and Trade Marks Department,
New Oxford Street, London, WC1A 1QJ

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(54) A liquid crystal display illumination system

(57) An illumination system is provided for a liquid crystal display panel. The panel 1 is placed to transmit light 2 from a light source 3 to a viewing location, the light source being an extended area source of omnidirectional light of high efficiency, such as a fluorescent tube. A light guide 6 is placed between the source and the panel, the light guide comprising a transparent input face 7 adjacent the source, a transparent output face 10 adjacent the panel, and reflective side walls 11 transverse to the input and output faces. The light guide is tapered, the input face being smaller in area than the output face. The divergence of light from the source is thereby reduced as it passes through the panel. The LCD panel then functions with an improved contrast range. A lens may be provided at the wide end of the guide and a diffuser in front of the LCD panel. The light guides may be hollow or solid. The display arrangement may be used in a television receiver or in an aircraft head-up display.
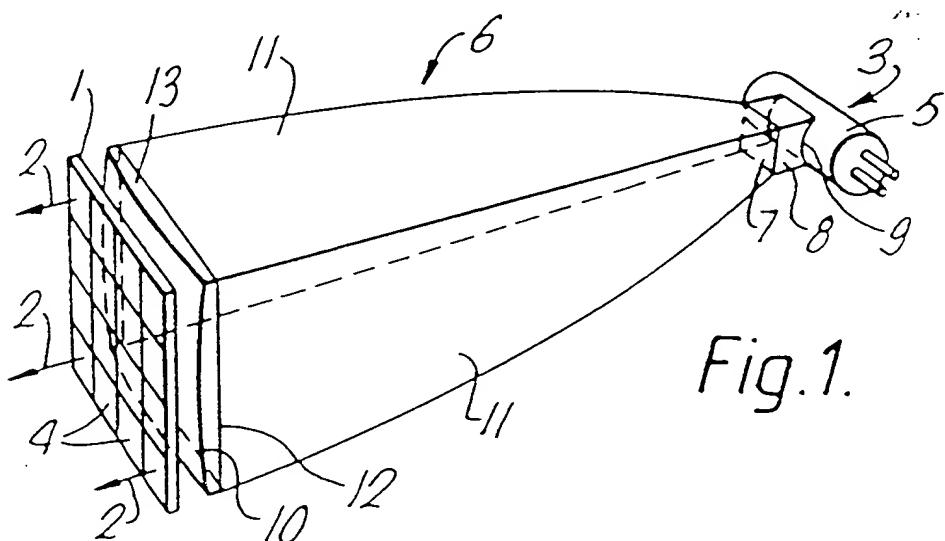


Fig.1.

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**Fig.1.**

**Fig.2.**

**Fig.3.**

**Fig.4.**

**Fig.5.**

51

50

**Fig.6.**

90  85  86  87  88  80

89

91

81

82

83

84

A

B

94 95

85

96

97

A

**Fig.7.**

92

93

**Fig.8.** 101 104 100 103 120

**Fig.9.** 104 105 102 100 106

**Fig.10.** 98 106

**Fig.11.** 61 60 61 60 61

**Fig.12.** 72 71 70

**Fig.13.** 131 134 135 132 136 133 130
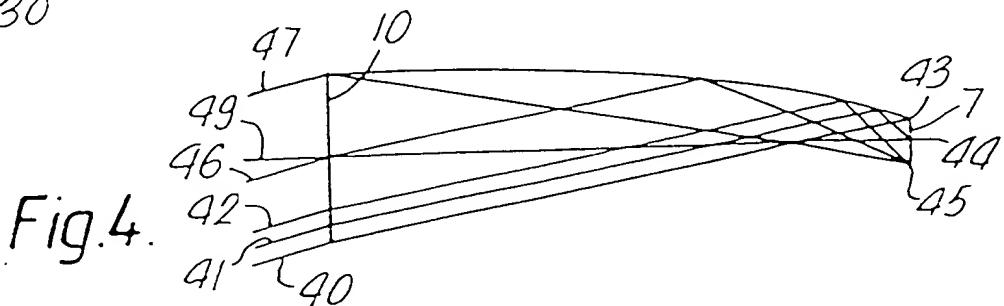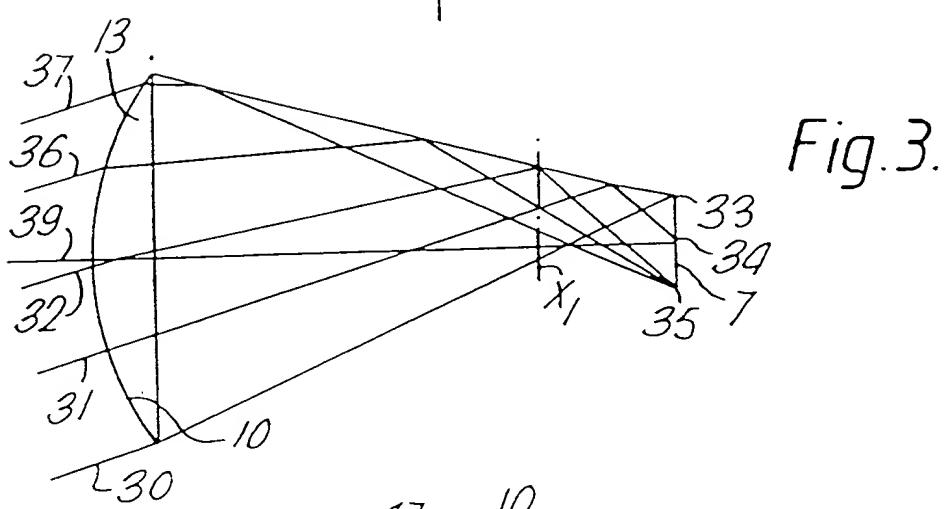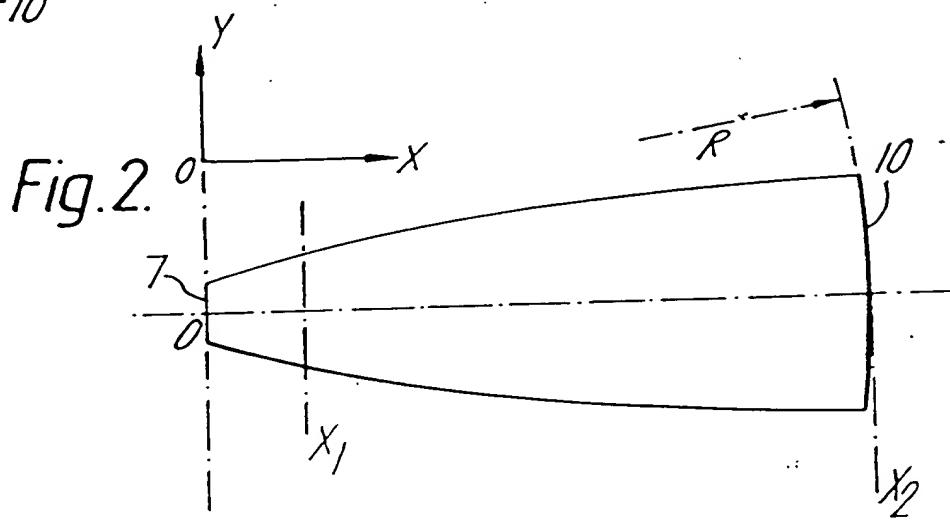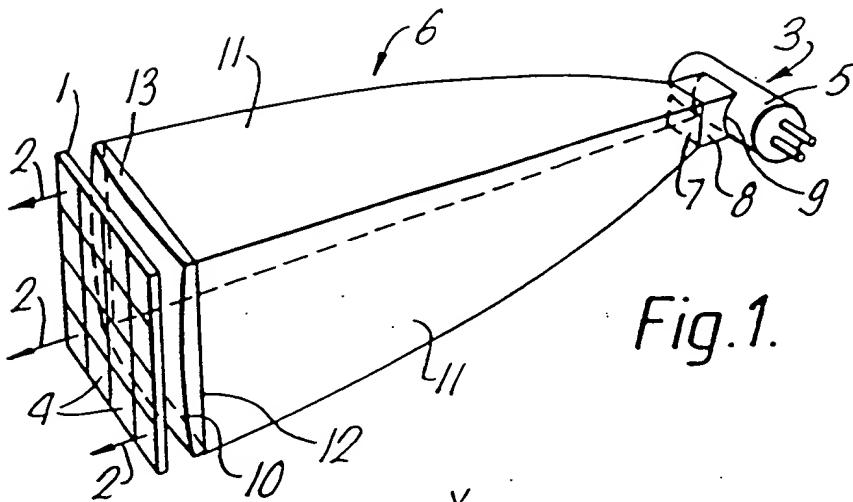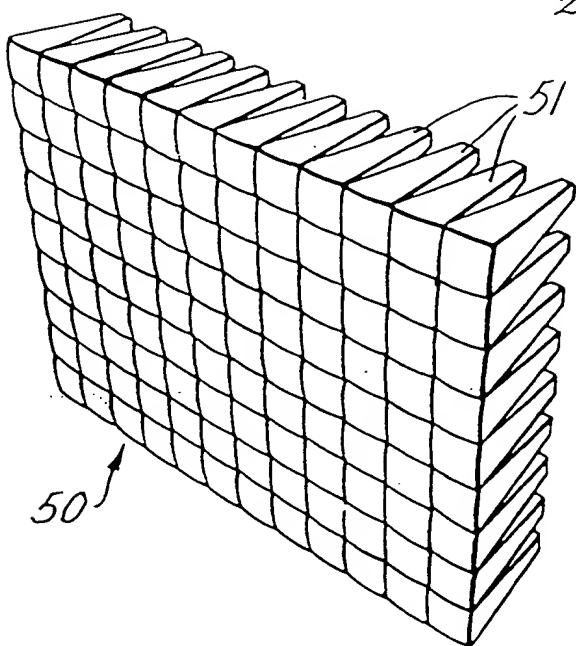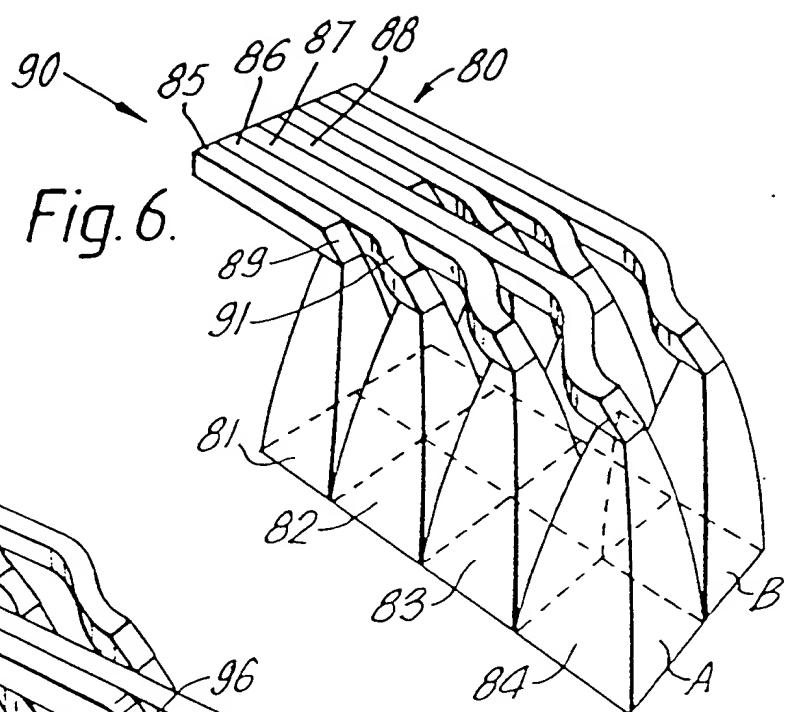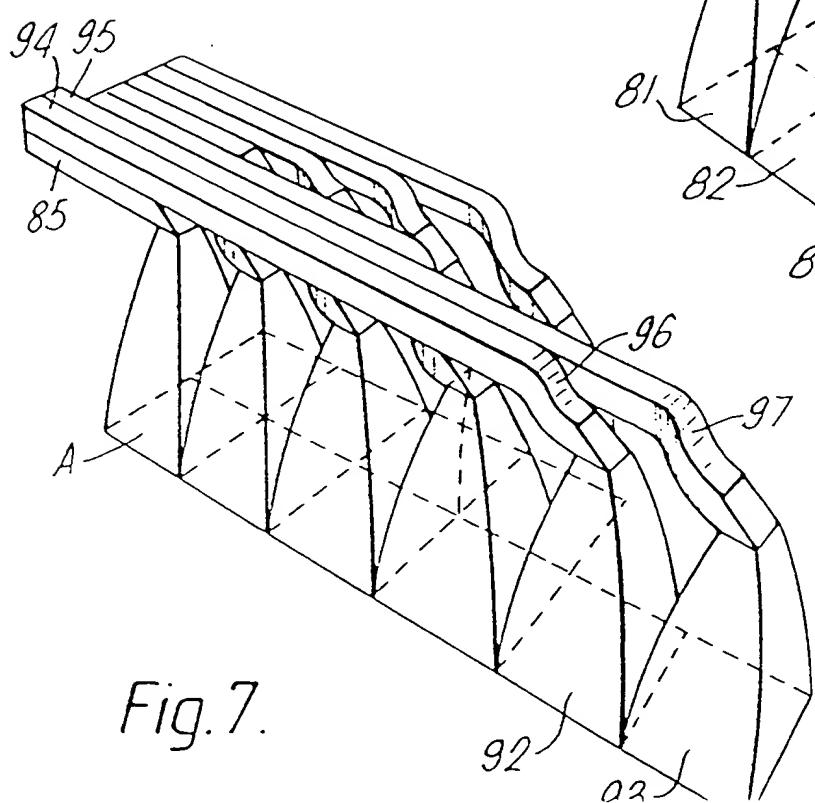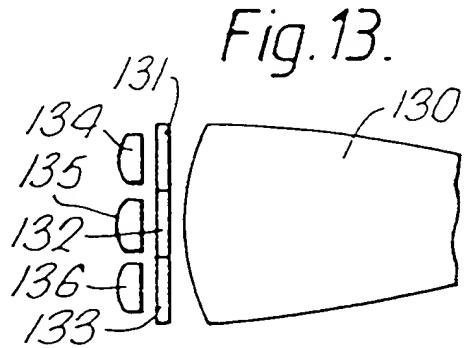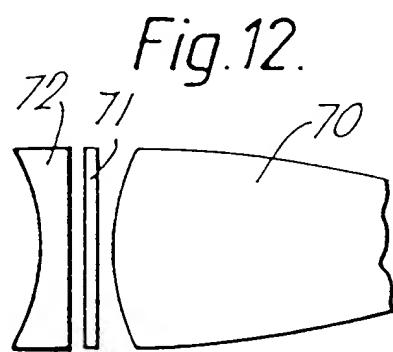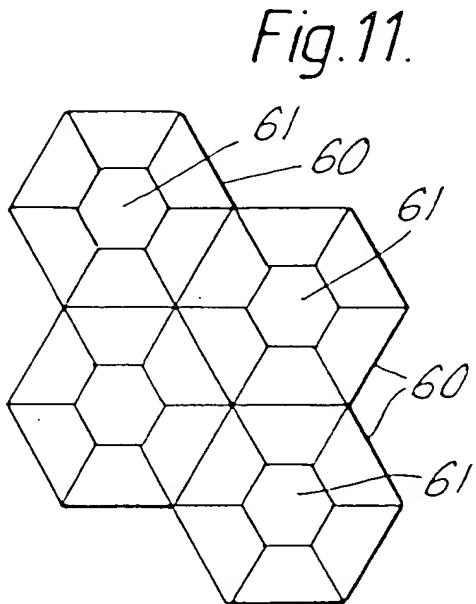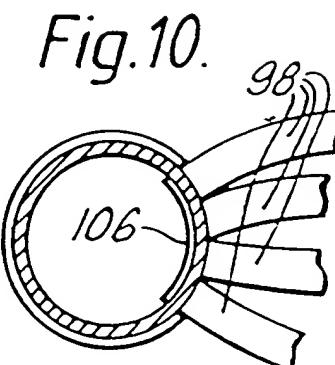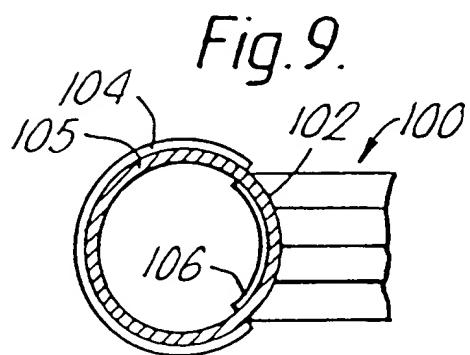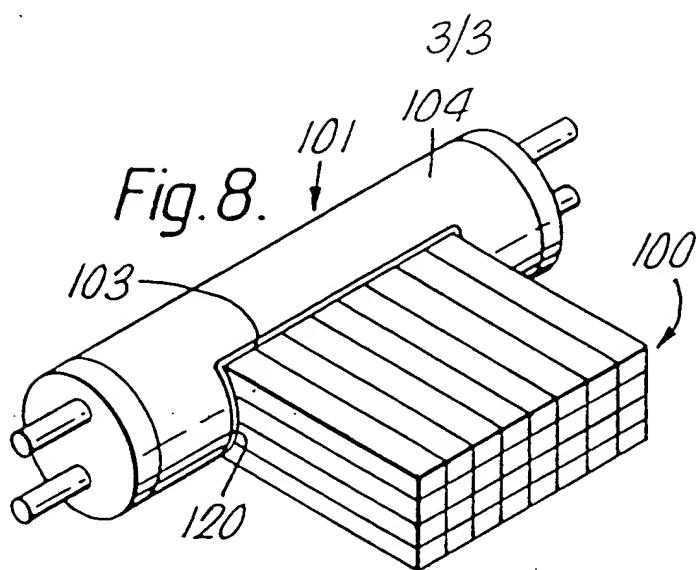
DESCRIPTION

A LIQUID CRYSTAL DISPLAY ILLUMINATION SYSTEM

This invention relates to illumination systems for passive electro-optic display panels of the kind which can be used to display television pictures for example. The panels are passive in the sense that they do not generate light but modulate the brightness of incident illumination to provide modulated light for each of the picture elements in the picture displayed. More particularly the invention relates to an illumination system for a liquid crystal display panel wherein the panel is placed to transmit light from a light source to a viewing location.

Such illumination systems are described in European Patent Applications 0,192,023A and 0.193,401A wherein projection television systems using liquid crystal panels are described. Both these systems use high intensity concentrated light sources and optical systems comprising mirrors and lenses to pass light through the panel. Projection lenses are then used to produce an enlarged image on a viewing screen. The light sources are therefore usually tungsten filament lamps of relatively low efficiency, requiring relatively high power and producing considerable heat which has to be dissipated as in EP 0,192,023A.

The present invention is more applicable to direct view television apparatus and, with portability and power economy in mind, is concerned with the use of high efficiency light sources. Such sources are usually phosphor layers of extended area emitting visible light when stimulated by electrons or by ultraviolet radiation generated in a gas discharge, such as in the well known fluorescent tube.

The light from such a phosphor layer is emitted into the full hemisphere, the layer appearing equally bright at all angles of view of the layer surface. Such light applied directly to a liquid crystal display panel would therefore pass through the panel in a wide range of angles. For many types of liquid crystal panel the desired function of modulating the intensity of the transmitted light for each picture element in accordance with

a signal, is only obtained with a good range of contrast over a relatively small range of light angles, typically ± 10 degrees, to the normal to the panel. At larger angles of incidence of the light, the contrast range is unacceptably degraded.

5      It is an object of the invention to enable high efficiency phosphor light sources to be used to iluminate a liquid crystal display panel by transmission and yet achieve an acceptable contrast range in the image displayed. The invention provides an illumination system for a liquid crystal display panel wherein

10    the panel is placed to transmit light from a light source to a viewing location, characterised in that the light source is an extended area source of omnidirectional light, in that a light guide is placed between the source and the panel, the light guide comprising a transparent input face adjacent the source, a

15    transparent output face adjacent the panel, and reflective side walls transverse to the input and output faces, and in that the light guide is tapered, the input face being smaller in area than the output face. Light enters the input face of the tapered guide over a wide range of angles but reflection from the side

20    walls reduces the range of angles present in the light emerging from the output face. Increasing the ratio of the output face area to the input face area is effective in reducing the range of angles, away from the normal to the output face, which is present in the output light. However, reducing the range of angles also

25    increases the ratio of the length of the light guide to the linear dimensions of the output face.

A material improvement in reduction of the relative length is obtained in such an illumination system characterised in that the output face comprises a positive lens. The effect of the

30    lens is to refract light generally towards the guide axis, that is, to act as a collimating lens. For a given range of output angles the length of the guide can be materially reduced, leading to a more compact apparatus.

The guide may be hollow and may be internally reflective.

35    Alternatively, the invention may be characterised in that the

guide comprises a transparent material of a refractive index higher than that of the surrounding space whereby the side walls are reflective by total internal reflection. In this event the output face may be convex toward the panel thereby forming a positive lens.

The illumination system in accordance with the invention may be further characterised in that the side walls are curved in planes transverse to the input and output faces. The shape of the side walls can be chosen either to reduce the divergence of the output light or, in conjunction with the positive lens, to shorten the guide for a given divergence. Parts of a guide wall may be convex and other parts concave in some possible designs of guide. To obtain efficient reduction in divergence angles and reasonably sharp cut-off angles, special optical design techniques are employed. These special optical design principles of the tapered guide of the present invention are identical to those of the non-imaging concentrators of radiation designed, for example, for use as concentrators of solar radiation. The only difference between the guide and the concentrator being the reversed direction of the radiation. The design principles are covered in a book entitled "The optics of nonimaging concentrators" by W. T. Welford and R. Winston, Academic Press 1978 in chapters 4, 5 et seq., and will not be further referred to here except to give examples of guide shapes obtained for various values of the design parameters.

The invention may be further characterised in that a plurality of illumination systems are assembled so that the output faces of the light guides are adjacent to one another to cover the whole area of an extended liquid crystal display panel. If the output faces are identical to one another they may be arranged in regular rows and columns. Rectangular output and input faces may be used, though other shapes, such as triangular or hexagonal faces may be used.

For high efficiency of conversion of electrical energy to light, the illumination system may be characterised in that the

source comprises a phosphor layer energised to produce light.
The phosphor layer may be energised by ultra-violet radiation
from a gas discharge in a fluorescent tube, making use of a light
source of high brightness and high reliability.  For high

5  efficiency in use of light from the phosphor layer in the case
where a plurality of light guides are used, the illumination
system may be characterised in that feeder light guides are
provided one each for the tapered light guides, each feeder guide
coupling an area of the source to the input face of the

10  associated tapered guide.

To improve viewing conditions the illumination system may be
characterised in that a light-diffusing screen is placed adjacent
to the liquid crystal display panel on the side remote from the
light guide.  The light emerging from the liquid crystal display

15  panel is then spread and is visible from a reasonably wide range
of angles.  A displayed television picture, for example, can then
be seen by several people sitting side-by-side.

Embodiments of the invention will now be described with
reference to the accompanying drawings in which,

20  Figure 1 shows an illumination system in accordance with the
invention,

Figure 2 shows a coordinate system used to describe the
guide wall shape,

Figures 3 and 4 show ray paths in two examples of light

25  guide,

Figure 5 shows a rectangular array of tapered light guides
for use in illuminating an extended area liquid crystal display
panel,

Figure 6 shows an array of guides with feeder light guides,

30  Figure 7 shows the Figure 6 array with part of a second
layer of feeder light guides,

Figure 8 shows an arrangement for coupling feeder light
guides to a fluorescent tube,

Figure 9 shows a cross-section of an alternative form of

35  fluorescent tube light source.

Figure 10 shows an alternative arrangement for coupling feeder light guides to a fluorescent tube,

Figure 11 shows a front view of part of an array of guides of hexagonal cross-section,

Figure 12 shows a side view of a tapered guide for illuminating one or more picture elements and having a light diffusing lens structure and,

Figure 13 shows light guide illumination for a triplet of liquid crystal elements, each with a light diffusing lens structure.

Referring to Figure 1, an embodiment of an illumination system for a liquid crystal display panel is shown in accordance with the invention. A liquid crystal display panel 1 is placed to transmit light 2 from a light source 3 to a relatively distant viewing location, not shown, off to the left of Figure 1. The panel is shown divided into sixteen separate pixels (picture elements) 4, largely for clarity in the drawing. The panel may in practice, at one extreme, comprise an array of pixels equal in number to those in a normal television picture. At the other extreme, the panel may comprise a single pixel, a television picture being assembled from an array of such pixels, each with its own illumination system. In between these extremes the panel may be proportional to provide a subset of pixels of the whole television picture, an array of such panels being assembled to provide all the pixels of the T.V. frame.

The light source 3 comprises a fluorescent tube having an extended area of phosphor energised by ultra-violet radiation from a mercury gas discharge in the well known manner. The phosphor is very nearly a Lambertian emitter, that is to say the phosphor on the inside of the glass envelope 5 appears equally bright at all angles of view to the surface. The cylindrical envelope of the tube then appears as a bar of light of uniform brightness across its width. Each point on the phosphor surface therefore emits light omnidirectionally. A light guide 6 is placed between the source 3 and the panel 1. In this example the

guide 6 may consist of a transparent plastics material, such as polymethylmethacrylate (PMMA), and has a transparent input face 7 either placed directly in contact with the tube 3 or coupled by a parallel sided guide 8 to the cylindrical surface 9 of the

5      fluorescent tube.    The guide 6 has a transparent output face 10 adjacent the panel and covering the area of panel 1.   In this example the guide is.shown having a square cross-section.  Guide 6 is tapered, the input face 7 being smaller in area than the output face 10.   In this example, the linear dimension of the

10     output face is four times that of the input face so that the input face area is one sixteenth of the output face area.   The walls 11 of the guide are polished smooth and are reflective to light inside the guide by virtue of the total internal reflection (T.I.R).  The refractive index of PMMA is 1.495 so that the

15     critical angle for T.I.R. is 42 degrees, light incident on the walls internally at angles to the normal greater than 42 degrees being totally reflected back into the guide.  The parallel sided guide 8, used to feed light from the source to the input face is also polished smooth on all its faces and is in optical contact

20     with the input face 7 so that there are no refraction or reflection effects at the interface.  The input face 9 of guide 8 will typically be in touching but not optical contact with the cylindrical surface of the tube.  The input face 9 is shown curved to fit the cylindrical envelope 5 in the Figure 1

25     embodiment, but it could equally well be flat.
       In order to ensure a sealed interface between the guide and tube to exclude scattering or absorbing contaminants, the guide may optionally be optically bonded to the tube.  In this case, a proportion of the light entering the guide escapes from the guide

30     at first incidence because it is less than the critical angle.  A light absorbing jacket, not shown, may optionally be provided around the tapered guide, but not inoptical contact with it, to remove stray light.

       The end 12 of the guide 6 is shown as flat and optically

35     bonded to a plano-convex lens 13, which may possibly be of

the same material as the guide, in which case the guide and lens may be made as one piece. The action of the lens 13 is to provide a general collimating effect on divergent light emerging from the guide, reducing the length of the guide.

5    The action of the tapered guide in reducing the divergence of light entering the small input face, passing down the guide, and leaving by the large output face is covered in detail, with the light direction exactly reversed, in the book by Welford and Winston cited in the preamble of this specification. Therein the

10    action of non-imaging radiation concentrators is analysed in detail. In these concentrators fairly highly collimated radiation, usually direct sunshine, is taken in over a large area (analogous to our output face) and concentrated in a highly divergent form on a desirably much smaller area radiation

15    collector (analogous our input face). The collector is either a heat collector in which it is desired to produce as high a temperature as possible or is a photovoltaic collector which is desirably of small area in view of the high relative cost of these devices. However the divergence reducing action of the

20    tapered guide can be seen from the fact that a ray from the small input face passing down the guide at an angle to the guide axis will strike a reflective side wall which is itself inclined away from the guide axis because of the designed taper and will therefore be reflected back into the guide at a smaller angle to

25    the guide axis than it had before reflection. In contrast, in a parallel sided guide no change of a ray angle magnitude to the guide axis occurs. One reflection may be sufficient to reduce the divergence to the desired extent.

With many types of liquid crystal displays it is desirable

30    that the divergence of the light passing through the liquid crystal layer should be no greater than ± 15 degrees, and preferably ± 10 degrees, to obtain a full contrast range. This is a fact well known from the operation of the layer in attenuating light passing through it to a controlled extent.

35    The desired maximum divergence is determined by the ratio of

the dimensions of the input and output faces.  If the light guide
is to have the ideal characteristic of sharp cut-off angles, the
profile of the guide is determined in relation to the power of
the positive lens on the output face.  Figure 2 shows an XY

5   coordinate system which will be used to describe the profiles of
some examples of guides.  In these examples the profiles are in
two parts, the first part extending from X=0 at the input face 7
to X=$X_1$, the second part extending from X=$X_1$ to X=$X_2$ at the
output face 10 with a smooth transition between the two parts at

10  X=$X_1$.  The output face 10 can have a substantially spherical or
cylindrical radius of curvature R.  It could also be compounded
of two cylindrical surfaces superposed with their cylinder axes
at right angles.  The guide is symmetrical about the X axis, each
positive Y ordinate having an equal negative Y ordinate.

15      Figure 3 shows ray paths in a tapered light guide having a
positive lens 13 on the output face.  The ratio of the linear
dimension of the output face to the input face is four to one, as
it is in Figure 4 which shows a guide with a flat output face.
In Figure 3 rays 30, 31 and 32 originate from three points 33, 34

20  and 35 respectively on the input face having entered at the
critical angle, that is, as the greatest angle to the axis 39
that is possible for them.  These rays are reflected off the
first part of the profile and all emerge at approximately 15
degrees to the axis after passing through lens 13.  Rays from any

25  part of the input face at smaller angles to the axis but directed
at a wall are reflected at least once off some part of the wall
to emerge at 15 degrees or less to the axis, rays 36 and 37 being
examples of rays from point 35, ray 37 being incident on the wall
with a larger angle of incidence than ray 36.  After passing

30  through lens 13 rays 36 and 37 emerge at approximately 15 degrees
to the axis 39.  Any ray from the input face not incident upon a
wall is incident directly on the lens 13 and emerges at an angle
of less than 15 degrees on one side or other of the axis 39.  For
clarity only rays on one side of the axis are shown, rays on the

35  other side being a mirror image of those shown.

In Figure 4 the rays from corresponding points have the same units numeral as the rays in Figure 3. It will be seen that the absence of the positive lens on the output face necessitates a considerably longer guide in relation to the input and output face dimensions.

There now follows five particular examples of numerically defined profiles. The first two examples show how the length of the light guide is dependent on the radius of the curved output face. They have identical input and output apertures, and are made of the same material. Dimensions are given in arbitrary units, since the guides would be scaled up or down in size to suit the particular application.

EXAMPLE 1

An angle reducing light guide with maximum output angle of +/-15 degrees in which the input aperture is 2.5, the output aperture is 10.0, and length is 29.58.

The input face is flat, and the output face is curved with a radius of 40.0 convex to the outside. The light guide is made of a material which has a refractive index of 1.495, such as PMMA or an appropriate glass.

The profile of the curved side surfaces of the light guide is given by the equation:

$$y = A_0 + A_1x + A_2x^2 + A_3x^3 + A_4 x^4 + A_5x^5 + A_6x^6$$

where x is the distance along the axis of the light guide measured from the flat input face, y is the height of the profile above this axis, and $X_0$ to $A_6$ are coefficient as given below.

The profile is in two sections with a smooth transition at the join.

From x = 0 to x = 3.987, the coefficients are

$A_0 = 1.25$          $A_1 = .26724$

$A_2 = .0014813$      $A_3 = -6.1900 \times 10^{-5}$

$A_4 = 2.0518 \times 10^{-5}$    $A_5 = -3.1565 \times 10^{-6}$

$A_6 = 1.5685 \times 10^{-7}$

From x = 3.987 to x = 29.268, the coefficients are

$A_0 = .84297$        $A_1 = .50218$

$$A_2 = -.040047 \qquad A_3 = .0023612$$
$$A_4 = -8.7589 \times 10^{-5} \quad A_5 = 1.7890 \times 10^{-6}$$
$$A_6 = -1.5248 \times 10^{-8}$$

EXAMPLE 2

An angle reducing light guide similar to Example 1, with maximum output angle of +/-15 degrees in which the input aperture is 2.5, and the output aperture is 10.0, but with a much reduced length of 16.65.

The input face is flat, and the output face is curved with a radius of 8.0 convex to the outside. The light guide is made of a material which has a refractive index of 1.495, such as PMMA or an appropriate glass.

The profile of the curved side surfaces of the light guide is given by the same equation as in Example 1, the coefficients being given below.

The profile is in two sections with a smooth transition at the join.

From $x = 0$ to $x = 3.765$, the coefficients are

$$A_0 = 1.25 \qquad A_1 = .16957$$
$$A_2 = .0027063 \qquad A_3 = -.0055697$$
$$A_4 = .0014544 \qquad A_5 = -2.3040 \times 10^{-4}$$
$$A_6 = 1.5915 \times 10^{-5}$$

From $x = 3.765$ to $x = 14.894$, the coefficients are

$$A_0 = .75325 \qquad A_1 = .49699$$
$$A_2 = -.050965 \qquad A_3 = .0055546$$
$$A_4 = -3.4068 \times 10^{-4} \quad A_5 = 1.1334 \times 10^{-5}$$
$$A_6 = -1.5974 \times 10^{-7}$$

The next example shows how smaller output angles may be obtained and how other materials may be used. The dimensions given are smaller to indicate that a large number of very small light guides may be used with consequent reduction of the depth of the system. It is possible to have one light guide for each picture element, light feed arrangements being shown later.

EXAMPLE 3

An angle reducing light guide with maximum output angle of +/-10 degrees in which the input aperture is 0.1667, the output aperture is 1.0, and length is 2.965.

The input face is flat, and the output face is curved with a radius of 2.0 convex to the outside. The light guide is made of a material which has a refractive index of 1.57, such as polycarbonate or an appropriate glass.

The profile of the curved side surfaces of the light guide is given by the equation as before, the coefficients being given below.

The profile is in two sections with a smooth transition at the join.

From $x = 0$ to $x = 0.2966$, the coefficients are

$A_0 = 0.08333$ $\qquad$ $A_1 = .25167$

$A_2 = .031721$ $\qquad$ $A_3 = 0.17636$

$A_4 = -1.1428$ $\qquad$ $A_5 = 3.4221$

$A_6 = -3.9087$

From $x = 0.2966$ to $x = 2.901$, the coefficients are

$A_0 = .060727$ $\qquad$ $A_1 = .43015$

$A_2 = -.36564$ $\qquad$ $A_3 = .24897$

$A_4 = -.10125$ $\qquad$ $A_5 = .022138$

$A_6 = -.0019918$

The next example has similar output angles to Example 3, and also shows how an output lens of different material may be used. The dimensions given are larger to indicate that a small number of large light guides may be used with consequent increase in the depth of the system. It is possible to have one light guide for the whole picture.

EXAMPLE 4

An angle reducing light guide with maximum output angle of +/-10 degrees, in which the input aperture is 33.3, the output aperture is 200, and length is 253.5.

The main part of the light guide has flat input and output faces, and is made of a material which has a refractive index of 1.495, such as PMMA or an appropriate glass. A plano-convex lens

with a radius of 150 on the convex surface, and made of a glass
or plastic material with refractive index 1.75, is cemented or
moulded to the output face.

The profile of the curved side surfaces of the light guide
is given by the equation as before, the coefficients being
given below.

The profile is in two sections with a smooth transition at
the join.

From x = 0 to x = 54.92, the coefficient are

$A_0$ = 16.6677 $\quad\quad$ $A_1$ = .16279

$A_2$ = .0054678 $\quad\quad$ $A_3$ = $-1.6460 \times 10^{-4}$

$A_4$ = $4.0225 \times 10^{-6}$ $\quad\quad$ $A_5$ = $-5.2560 \times 10^{-8}$

$A_6$ = $2.7652 \times 10^{-10}$

From x = 54.92 to x = 232.2, the coefficients are

$A_0$ = 9.99533 $\quad\quad$ $A_1$ = .49150

$A_2$ = $-.0023410$ $\quad\quad$ $A_3$ = $2.2415 \times 10^{-5}$

$A_4$ = $-1.1317 \times 10^{-7}$ $\quad\quad$ $A_5$ = $2.9714 \times 10^{-10}$

$A_6$ = $-3.1977 \times 10^{-13}$

An examination of the profiles in Example 2 shows that they
approximate to linear profiles over most of their length. It is
therefore possible to design a light guide which is of much
simpler construction, but with a performance slightly inferior to
a light guide which has the ideal shape. The most noticeable
effect will be that the cut-off of the output angle will not be
so sharp.

EXAMPLE 5

An angle reducing light guide similar to Example 2, with
nominal output angle of +/-15 degrees, in which the input
aperture is 2.5, and the output aperture is 10.0, and with a
length of 16.65.

The input face is flat, and the output face is curved with a
radius of 8.0 convex to the outside. The light guide is made of
a material which has a refractive index of 1.495, such as PMMA or
an appropriate glass.

The profile of the side surfaces of the light guide is given

by the simplified equation:

$$y = A_0 + A_1 x$$

where x is the distance along the axis of the light guide
measured from the flat input face, y is the height of the profile
above this axis, and $A_0$ and $A_1$ are coefficients as given below.

The coefficients for the profile are

$$A_0 = 1.25 \qquad A_1 = .25179.$$

All the light guides in the examples given have been solid
transparent bodies, using total internal reflection to produce
reflective side walls. To give a light weight structure, the
guides can alternatively be hollow shapes with relatively thin
walls coated on the inside with a reflective layer. The input
and output faces then have no interface surface, except when a
positive lens is attached over the output face.

In the event that a television picture is displayed, the
output light divergence of ±15 degrees or less may not render the
picture visible over a sufficient range of angles, particularly
in the horizontal plane, to accommodate a number of viewing
persons seated in a row in front of the picture. A diffusing
screen may then be placed adjacent to the liquid crystal display
panel on the side remote from the light guide. A simple diffuser
such as a ground glass surface may spread the output light in the
vertical plane, towards the ceiling and floor of the room where
it is not required and with the consequence that the brightness
of the picture seen by the viewers in the horizontal plane is
reduced. A vertically oriented lenticular lens system may be
preferable with a separate vertical cylindrical lens for each
column of picture elements or for a number of columns of picture
elements. The angle of light spread in the horizontal plane can
then be controlled with little spread in the vertical plane.

However, in other application the limited divergence of
light output from the guides may not be a disadvantage and may
even be turned to advantage. In applications where there is only
one viewer, such as the head-up display in a single seat aircraft
cockpit, the limited divergence would be no disadvantage. In

bank terminals, cash-points, and the like, the limited divergence would assist in providing a display restricted to viewing by the user only.

Figure 5 shows a rectangular array 50 of 108 square output face tapered light guides 51 arranged in a 12x9 array to cover an extended area liquid crystal display panel having an aspect ratio of 4:3 as required for a television picture. Thus each guide illuminates one ninth of the height or about 67 lines of a nominal 625 line picture.

Figure 6 shows a small part of the array of Figure 5 with a feeder light guide arrangement 80 for feeding each of a column A of tapered guides with light from a common source. A column of four adjacent guides 81, 82, 83 and 84 are shown fed by a close-packed assembly of four parallel-sided square-section solid feed guides 85, 86, 87 and 88 respectively. Feed guide 85 is straight with a 45 degree face 89 opposite the input face of guide 81. Light 90 fed into guide 85 passes by T.I.R. down the guide and is reflected, also by T.I.R., by face 89 into the guide. Guide 86 is also initially straight and is close packed alongside guide 85 to which it may or may not be bonded in optical contact. Spreading of light 90 between the parallel parts of the feed guides may be of assistance in equalising the light inputs to the guides. A solid, mechanically robust light feeder guide assembly may be desirable. Guide 86 has a swan-neck portion 91 to bring its output end into line with the second guide 82 of the column. Feeder guides 87 and 88 are very similar, differing only in being progressively longer and having more accentuated swan-neck portions.

Figure 6 shows a second column B of four tapered guides fed by a set of four feeder guides identical to guides 85, 86, 87 and 88. The input ends of the eight guides are arranged in a line to face a planar light source.

Figure 7 shows the first two guides 92, 93 of a four guide column extension to column A of Figure 6. The respective feeder guides 94 and 95 are stacked immediately above and parallel to

guides 85 and 86 respectively. The swan-neck portion 96 is
provided to lower the guide 94 onto the input face of tapered
guide 92. The swan-neck portion 97 not only brings the output
end of the feeder guide into line with column A but also lowers
it to meet the input face of tapered guide 93. The feeder guides
are preferably in optical contact with, and could be mechanically
bonded to, their respective tapered guides. This avoids an
optical interface where scattering and loss of light by
contaminants might occur and also provides mechanical robustness.

Figure 8 shows an arrangement for coupling a bundle 100 of
close-packed feeder guides to a fluorescent tube 101. The end
102 of the bundle is formed into a polished cylindrical surface
to fit the glass envelope 103 of the tube and is butted against
it. Except in the area of the tube facing bundle end 102, the
fluorescent tube has a reflective layer 104 to reflect light back
into the tube. After scattering, some of this reflected light
will emerge from the tube opposite bundle end 102 increasing the
quantity of light entering the feeder guides.

Figure 9 shows a cross section of an alternative form of
fluorescent tube light source. The envelope 105 of the tube is
made of quartz, or other material transparent to the 365 nm line
of the mercury gas discharge. The reflective layer 104 is
present in the same position and extent as in the Figure 8 tube.
However, there is no phosphor on the inside of the tube opposite
the reflective layer, only opposite the bundle end 102 at 106.
Thus light is only produced immediately adjacent to the bundle
end, the reflective layer 104 acting to concentrate ultra-violet
radiation on the phosphor. Light absorption losses are therefore
much reduced as compared to the Figure 8 tube. The power
consumption of the Figure 9 tube can therefore be reduced for a
given phosphor brightness.

Figure 10 shows the feeder guides of Figure 9 separated, 98,
each being normal to the phosphor layer 106 so that the
illumination conditions at the guide inputs are more nearly
identical.

Figure 11 shows a front view of part of a close-packed array of hexagonal cross-section light guides. The hexagonal output faces 60 are close-packed, the input faces 61 being separated but still arranged in columns. Thus a feeder guide arrangement as shown in Figures 6 and 7 can be used to feed the hexagonal guides, the only changes being that each feeder guide would be hexagonal in cross-section, and alternate columns would have different length feeder guides.

Desirably, it should be possible to display a colour television picture. In this event each pixel is a cluster of three sub-pixels, red, blue and green. If the picture is viewed at angles away from the normal to the panel, the relative brightnesses of the three sub-pixels in a pixel should not change as a function of viewing angle, otherwise the hue of the pixel will change as a function of angle. The absolute brightness of the pixel may well fall off with increasing angle of view. It is important, therefore, that the horizontal light diffusion polar diagram should be well controlled and equal for the three sub-pixels of any pixel. Figure 12 shows a tapered guide 70 illuminating one or more pixels or sub-pixel panel area 71. A positive or negative power lens array 72 is provided beyond the panel 71, the figure showing the cross-section of a cylindrical lens accepting light from a vertical column of panels 71 normal to the plane of the drawing. The light diffusion polar diagram can be controlled via the choice of the lens power. Being a lens rather than a scattering element, there is much lower loss of light by scattering, the light being directed only where it is required.

Figure 13 shows a tapered guide 130 feeding a single pixel having three sub-pixels 131, 132, 133 with positive lenticular lenses 134, 135, 136 respectively, the sub-pixels being the red, blue and green parts of a colour pixel. Light passing through each sub-pixel is brought to a focus immediately in front of the lens and diverges thereafter.

Returning to the array of Figure 5 and the feeder guide

arrangement of Figures 6 and 7, it is desirable that a single
source of light should illuminate the whole panel. Ageing of the
light source will then not produce differences in brighnesses
between pixels. But a column of tapered guides could be split
into two halves and a separate feeder guide arrangement be
provided for the two halves, each fed from its own light source.
A more compact display panel with fewer assembly problems would
result.

CLAIM(S)

1. An illumination system for a liquid crystal display panel wherein the panel is placed to transmit light from a light source to a viewing location, characterised in that the light source is an extended area source of omnidirectional light, in that a light guide is placed between the source and the panel, the light guide comprising a transparent input face adjacent the source, a transparent output face adjacent the panel, and reflective side walls transverse to the input and output faces, and in that the light guide is tapered, the input face being smaller in area than the output face.

2. An illumination system as claimed in Claim 1, characterised in that the output face comprises a positive lens.

3. An illumination system as claimed in Claim 1 or Claim 2, characterised in that the guide comprises a transparent material of a refractive index higher than that of the surrounding space whereby the side walls are reflective by total internal reflection.

4. An illumination system as claimed in Claim 3, characterised in that the output face is convex toward the panel thereby forming a positive lens.

5. An illumination system as claimed in any one of the preceding claims, characterised in that the side walls are curved in planes transverse to the input and output faces.

6. An illumination system for a liquid crystal display panel, characterised in that a plurality of illumination systems as claimed in any one of the preceding claims are assembled so that the output faces of the light guides are adjacent to one another to cover the whole area of an extended liquid crystal display panel.

7. An illumination system as claimed in Claim 6, characterised in that the output faces are identical to one another and are arranged in regular rows and columns to cover the extended display panel.

8. An illumination system as claimed in Claim 7,

characterised in that the output faces and input faces are rectangular.

9. An illumination system as claimed in any one of Claims 6, 7 or 8, characterised in that feeder light guides are provided one each for the tapered light guides, each feeder guide coupling an area of the source to the input face of the associated tapered guide.

10. An illumination system as claimed in any one of the preceding claims, characterised in that the source comprises a phosphor layer energised to produce light.

11. An illumination system as claimed in Claim 10, characterised in that the phosphor layer is energised by ultra-violet radiation from a gas discharge in a fluroescent tube.

12. An illumination system as claimed in Claim 11, characterised in that a part of the phosphor layer not coupled to a feeder guide is reflective to direct light back into the fluorescent tube and onto a part of the phosphor layer coupled to a feeder guide.

13. An illuminating system as claimed in Claim 11, characterised in that an envelope of the fluorescent tube is transparent to ultra-violet radiation, in that the phosphor layer is confined to the area of the tube envelope facing a feeder guide, and in that a part of the tube envelope not facing a feeder guide is reflective, to direct ultra-violet radiation back into the tube and onto the phosphor layer.

14. An illumination system as claimed in any one of the preceding claims, characterised in that a light-diffusing screen is placed adjacent to the liquid crystal display panel on the side remote from the light guide.

15. An illumination system as claimed in Claim 14, characterised in that the light diffusing screen comprises a cylindrical lens array.

16. An illumination system for a liquid crystal display panel substantially as described with reference to Figure 1 of

the accompanying drawings.

17.   An illumination system for a liquid crystal display panel substantially as described with reference to Figures 5, 6, 7, 8 and 9 of the accompanying drawings.

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